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Nielsen, S.P.

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Radioactive isotopes in Danish drinking water

Sven P. Nielsen
Risø National Laboratory

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Contents

Preface

This project for investigation of radioactivity in drinking water shall be seen as a documentation of the content of radioactivity in Danish drinking water. During revision of the Drinking Water Directive of the Council of the European Union (98/83/EU) radioactivity was included as a new parameter.

Most of the Danish drinking water (about 99%) is obtained from groundwater for what reason radioactivity in Danish drinking water is due mainly to naturally occurring radionuclides.

As the risk for high levels of radioactivity in the Danish Underground was assessed to be very low due to the information on the geological underground, the Danish Environmental Protection Agency (EPA) decided to do a national study on selected drinking waters. Selection criteria were:

- Important abstraction areas for the largest water supplies supplemented with
- Supplies distributed reasonably well over the country and
- Areas where the layers in the ground or the bedrock could indicate a higher risk.

The plan for the investigation was discussed and decided in co-operation between the Danish EPA, the National Institute of Radiation Hygiene (SIS) and Risø National Laboratory. The Geological Survey of Denmark and Greenland (GEUS) were consulted to help by selection of useful sampling point in areas with possibly increased levels of radioactivity.

All the water works selected to take part in this investigation have responded very positively and have been a great help for collecting the many samples. The Danish EPA will hereby thank the water works for their willingness and great help.

The project was carried out by Risø National Laboratory and followed by a Steering Committee with the following members:

Janne Forslund, Danish EPA (chairman)

Martin Skriver, Danish EPA

Kaare Ulbak, National Institute of Radiation Hygiene (SIS)

Carsten Israelson, National Institute of Radiation Hygiene (SIS)

Peter Gravesen, Geological Survey of Denmark and Greenland (GEUS).

Sven P. Nielsen, Risø National Laboratory (Project leader)

Per Roos, Risø National Laboratory

Sammenfatning og konklusioner

En screeningsundersøgelse af radioaktivitet i dansk drikkevand er gennemført i 2001-2003. Vandprøver er indsamlet fra 296 vandforsyninger, der repræsenterer over 40% af det drikkevand, der leveres fra danske vandværker. Koncentrationer af total alfa-radioaktivitet og total beta-radioaktivitet i vandprøverne er målt og sammenlignet med vejledende parameterværdier på 0.1 Bq/l alfa og 1 Bq/l beta radioaktivitet. For alle prøver var koncentrationerne af beta-radioaktivitet under parameterværdien, mens koncentrationerne af alfa-radioaktivitet for 13 prøver var over parameterværdien.

Der blev foretaget supplerende undersøgelser for vandværker i Ebeltoft, Grenå og Frederikssund, hvor koncentrationerne af alfa-radioaktivitet lå over parameterværdien, med henblik på at vurdere den samlede strålingsdosis (Total Indicative Dose, TID). De forhøjede niveauer af alfa-radioaktivitet skyldes hovedsageligt uran i vand fra enkelte boringer. Den årlige strålingsdosis fra indtag af vand med de højeste indhold af uran ligger betydeligt under den samlede strålingsdosis (TID) på 0.1 millisievert, som er grænseværdi for indhold af radioaktivitet i EU's Drikkevanddirektiv.

Der blev desuden indsamlet prøver af grundvand, der anvendes som drikkevand, fra områder med forskellig geologisk undergrund, så som grundfjeld og områder med mulighed for forhøjede niveauer af naturlig radioaktivitet. Også disse prøver viste indhold af radioaktivitet svarende til strålingsdoser betydeligt under grænseværdien fra Drikkevandsdirektivet.

På baggrund af undersøgelsens resultater er det sandsynligt, at risikoen er meget lille for at finde drikkevand i Danmark med uacceptabelt indhold af radioaktivitet. Der er derfor ikke behov for yderligere undersøgelser af radioaktivitet i dansk drikkevand, der stammer fra grundvand.

Summary and conclusions

A screening investigation of radioactivity in Danish drinking water has been carried out during 2001-2003. Samples of drinking water were collected from 296 water supplies representing more than 40% of the water delivered from water works in the country. Total alpha and total beta radioactivity was determined in the samples and compared with screening levels of 0.1 Bq/l total alpha and 1 Bq/l total beta radioactivity. The levels for total beta radioactivity were met in all the water works while total alpha radioactivity exceeded the screening levels for 13 water supplies.

Further investigations were carried out for the water works with concentrations of alpha radioactivity above the screening levels in Ebeltoft, Grenå and Frederikssund to estimate the total indicative dose from the water. The elevated levels were found to be due to uranium in the water from individual boreholes. Radiation doses from consumption of water at these uranium levels are estimated to be well below the total indicative dose of 0.1 mSv/y specified in the Drinking Water Directive

Groundwater used for drinking water was collected from different types of geological structures including bed rock and areas with potentially elevated levels of natural radioactivity. Also in these cases the concentrations of radioactivity were sufficiently low to meet the requirements in the Drinking Water Directive.

In view of the results it seems probable that the risk of finding drinking water in Denmark with unacceptable concentrations of radioactivity is very small. Therefore there is no need for further radiological investigations of the Danish water supply based on natural groundwaters.

1 Background

Shortly before the revision of the 1980 European Council Directive for drinking water finished in 1998, a set of parameters on radioactivity was introduced. The parameters for radioactivity included tritium and Total Indicative Dose (TID). The Directive requirements on radioactivity are that the concentration of tritium in drinking water does not exceed 100 Bq/l and that the TID does not exceed 0.1 millisievert (mSv) per year. The TID is the sum of radiation doses from radioactive isotopes present in the drinking water excluding tritium, potassium-40, radon and radon decay products. The TID cannot be measured by a single method. To overcome this problem additional parameters and measuring principles were needed.

During the following years the EU Commission introduced proposals for monitoring the TID in the Article 12 Committee, elected to update the Drinking Water Directive for sampling and monitoring purposes. These changes of the Directive were used for the present investigation. Because the work on radioactivity was still under way in the Article 12 Committee when the Danish Statutory Order transferred the Drinking Water Directive into Danish regulation, the Order did not require monitoring of the TID by the water works. Instead it is stated in the Order that investigation of the TID is carried out by the Danish Environmental Protection Agency.

The present investigation of radioactivity in Danish drinking waters is the result of the work the Danish Environmental Protection Agency has carried out to meet this obligation. The investigation took place during 2001-2003 and has included investigation of nearly 300 water works and single wells.

2 Scope of investigation

The scope of the investigation was to carry out a screening of radioactivity in drinking water for alpha and beta radioactivity from a representative number of the largest Danish water works all over the country. Special areas where higher levels of radioactivity could be expected were also included in the investigation

It was assumed that the Total Indicative Dose (TID) was below the parametric indicator value specified in the Directive if the screening levels for total alpha and beta radioactivity were not exceeded. If the screening levels were exceeded, further investigation of specific radioactive isotopes should follow. The TID is calculated from the radionuclide concentrations in the drinking water, dose coefficients from Directive 96/29/Euratom (EC, 1996) and an annual intake of 730 litres.

3 Description of Investigation

In Denmark there are approximately 3000 water works of which about 10% were selected for this investigation. The selected water works were primarily the major producers of drinking water across the country but included also water works from all over the country. Further locations, which for geological reasons could give rise to elevated levels of natural radioactivity in drinking water, were included. Most of the Danish drinking water (99%) is obtained from groundwater, the rest from surface water. Furthermore, 10 locations from a long-term routine monitoring programme operated by Risø National Laboratory on radioactivity in groundwater were included in the investigation.

Total alpha and beta radioactivity for water samples collected in 2001 were measured on dry solids from evaporated samples while the subsequent analyses during 2002 and 2003 were based on liquid samples concentrated by evaporation. If the measured concentrations of total alpha or total beta radioactivity exceeded the screening levels of concentrations of total alpha (0.1 Bq/l) and beta (1 Bq/l) radioactivity in drinking water new samples were taken and nuclide-specific analyses carried out. These analyses included determination of uranium and radium isotopes (^{234}U, ^{238}U and ^{226}Ra). In addition, analyses of radon in water were carried out on samples from water works on the island Bornholm where elevated levels could be expected and on Zealand.

By investigation of the dry solids of waters, isotopes like tritium and radon evaporate and are not included in the analyses. Specific analyses of tritium in drinking water were not considered relevant due to the absence of significant anthropogenic sources of tritium in Denmark. Determination of tritium in surface water and precipitation is covered by Risø's routine monitoring programme in Denmark and shows presently typical environmental levels of a few becquerels (Bq) per litre. Earlier in the 1960's, the levels of tritium in precipitation reached 100-300 Bq/l. The groundwaters extracted today may originate from precipitation fallen in the sixties. But monitoring in 1990 - 1995 of tritium in groundwater of all the 960 borings of the Danish Groundwater Monitoring Programme at different depths showed that concentrations of tritium were far below 10 Bq/l except for one boring at 12 Bq/l. The radiation dose per becquerel by ingestion is relatively low for tritium, so even a concentration of 300 Bq/l in drinking water causes only an annual dose of 0.004 mSv.

4 Radioactivity in Drinking Water

Radioactivity in drinking-water is principally derived from two sources:

- the leaching of radionuclides from rocks and soils
- the deposition of radionuclides from the atmosphere.

Naturally occurring radionuclides from both these sources account for almost the entire radioactivity present in Danish drinking water. Traces of man-made radioactive fallout from atmospheric nuclear weapons tests (conducted up to 1980) are detectable in the environment but their contribution to drinking water radioactivity is negligible.
The naturally occurring radionuclides originate in the Earth's crust where uranium, thorium and potassium are widely distributed and detectable in all soils and rocks. Uranium and thorium are radioactive, and each decays through a series of radionuclides to stable isotopes of lead, as shown in the decay schemes below. Only a very small percentage (0.0118%) of all potassium is the radioactive isotope potassium-40. It is not considered to be of radiological significance because potassium is an essential metabolic element and its levels in the body are in a state of equilibrium, and therefore do not vary significantly with dietary potassium levels.

Uranium series:
$^{238}U \rightarrow {}^{234}Th \rightarrow {}^{234}Pa \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra \rightarrow {}^{222}Rn \rightarrow {}^{218}Po \rightarrow {}^{214}Pb \rightarrow {}^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb \rightarrow {}^{210}Bi \rightarrow {}^{210}Po \rightarrow {}^{206}Pb$

Thorium series:
$^{232}Th \rightarrow {}^{228}Ra \rightarrow {}^{228}Ac \rightarrow {}^{228}Th \rightarrow {}^{224}Ra \rightarrow {}^{220}Rn \rightarrow {}^{216}Po \rightarrow {}^{212}Pb \rightarrow {}^{212}Bi \rightarrow {}^{212}Po$ or $^{208}Tl \rightarrow {}^{208}Pb$

where the symbols represent elements as follows:
Ac, actinium; Bi, bismuth; Pa, protactinium; Pb, lead; Po, polonium; Ra, radium; Rn, radon; Th, thorium; Tl, thallium; U, uranium.

The radionuclides in these decay series display a great range of radioactive half-lives from approximately 10^{10} years for ^{232}Th to 0.0001 seconds for ^{214}Po. Every radionuclide emits either alpha or beta radiation but their radiological significance varies. The solubility of thorium, for example, is so low, that it is only found in water as a component of suspended mineral particles. The natural radionuclides primarily regarded as being of radiological interest in drinking water appear in the following table.

Radionuclide	**Radiation**	**Half-life**
uranium - 238	alpha	4.5×10^9 y
uranium - 234	alpha	2.5×10^5 y
radium - 226	alpha	1600 y
radium - 228	beta	6.7 y
radon - 222	alpha*	3.8 d

* Radon decay products emit both alpha and beta radiation

Only water supplies from groundwater sources are likely to contain significant concentrations of these radionuclides, and the concentrations are as variable as the nature of the soils and rocks themselves.

While groundwater may contain natural uranium and thorium series radionuclides, surface water may contain radioactive material deposited from the atmosphere, including both natural radionuclides and materials from man-made sources such as nuclear weapons tests and satellite debris.

Because all radionuclides of interest emit alpha or beta radiation, their levels in drinking water may be assessed by measurement of the total alpha and beta activities.

The table below shows reference concentrations in drinking water of the most common natural and man-made radionuclides. The reference concentrations are based on the parametric value of 0.1 mSv per year for the Total Indicative Dose, dosimetric data for adults (EC, 1998) and assumed intake of 730 litres per year.

Origin	Nuclide	Reference concentration
Natural	Uranium-238	3.0 Bq/l
	Uranium-234	2.8 Bq/l
	Radium-226	0.5 Bq/l
	Radium-228	0.2 Bq/l
Man-made	Carbon-14	240 Bq/l
	Strontium-90	4.9 Bq/l
	Plutonium-239/240	0.6 Bq/l
	Americium-241	0.7 Bq/l
	Cobalt-60	40 Bq/l
	Caesium-134	7.2 Bq/l
	Caesium-137	11 Bq/l
	Iodine-131	6.2 Bq/l

5 Sampling

Drinking water samples for total alpha and beta measurements were collected in two-litre plastic bottles. Before filling the bottles, the water was allowed to flush for some time. Once returned to the laboratory, the water samples were treated as soon as practically possible. The time between sampling and evaporation ranged from 2 to 14 days.

Larger water samples of 25-50 litres were collected at selected water works and individual borings and used for analyses of uranium and radium.

Samples for radon analysis (10 ml) were taken at water works before and after treatment (aeration/oxidation) and transferred directly into counting vials ready for analysis.

6 Analytical Methods

6.1 Total Alpha and Beta Radioactivity

For water samples collected during 2001, aliquots of 300-500 ml water were evaporated completely in 60 mm diameter aluminium trays, which were subsequently measured in a multi sample proportional gas-flow counter for 1000 minutes. This proportional counter distinguishes events originating from alpha and beta decays by analysing the pulse height. Self-absorption of the alpha particles in the dry solids of the evaporated salt was corrected for based on measurements using a standardized uranium solution. No correction for absorption of beta particles was considered. Efficiency calibration was made using natural uranium and ^{90}Sr (^{90}Y) standards of known activity. Detection limits were calculated as three times the standard deviation of blank values and gave values of 0.01 Bq/l for total alpha and 0.03 Bq/l for total beta radioactivity.

For water samples collected during 2002 and 2003, aliquots of 200 ml water was transferred to a glass beaker and acidified with HCl to about pH 1. The water was evaporated until 1-5 ml was remaining depending on the salt content. The samples were never allowed to run dry. The remaining sample was transferred with a pipette to a liquid scintillation cell and the beaker washed twice with weak (about 1%) HCl, which was added to the sample. Once transferred to the liquid scintillation cell, 10 ml of 'Ultima Gold LLT'-scintillator cocktail was added and mixed thoroughly with the sample. The samples were counted for 150-200 minutes using a Wallac Quantulus 1220 liquid scintillation spectrometer. This spectrometer distinguishes events originating from alpha and beta decays by analysing the pulse shape. By adjusting the pulse shape analyser (PSA), alpha and beta activities are presented separately for the same sample. Blank and background samples were made by evaporating 200 ml distilled water at the same time as the samples. Counting of the blanks was done together with the samples. Efficiency calibration was made using $^{239+240}$Pu and ^{90}Sr (^{90}Y) standards of known activity. Detection limits were 0.01-0.03 Bq/l for total alpha and 0.03 Bq/l for total beta radioactivity. The detection limits were determined from blank samples (distilled water) evaporated simultaneously with the water samples and calculated as three times the standard deviation of blank values.

Different analytical equipment was used to determine total alpha and beta radioactivity during the project for what reason a comparison was made between results obtained from the gas-flow proportional counter and the liquid scintillation counter (LSC). Even though not ideal, samples previously measured on the gas-flow counter were dissolved and measured on the LSC. Furthermore, since water still remained from one of the stations (Feldbak) this was re-analysed and results compared with previous data.

The results of the test are presented in the following table.

Sample	Sample ID	Alpha (Bq/l)	Beta (Bq/l)
Pedersker 2001, proportional counter	1099	<0.01	0.58
Pedersker 2001, re-dissolved salt (LSC)	1099	<0.01	0.45

Feldbak 2001, proportional counter	1102	<0.01	0.83
Feldbak 2001, re-dissolved salt (LSC)	1102	0.03	0.48
Feldbak 2001, new evaporation (LSC)	1102	0.06	0.65

The variation between the results is acceptable considering the different methods used. For the Pedersker sample, the total beta results from the proportional counter and the LSC show a variation around the mean value corresponding to an 18% standard deviation. A significant difference was found between LSC and gas-flow measurements for the Feldbak total beta. This may partly be due to the delay in time between the two measurements. The two LSC measurements performed (re-dissolved salts and new evaporation) were done comparatively close in time and therefore may show less difference. One reason for the relatively small difference between the two techniques may be that the correction for self-absorption on the evaporated samples measured on the gas-flow counter was calibrated using natural uranium. Since uranium was the major contributor in samples from several water works this correction was probably unusually correct. For LSC no severe corrections for self absorption (apart from quenching) were necessary.

6.2 Uranium

For samples collected during 2001 and 2002, uranium was determined by alpha spectrometry on large (25-50 litres) samples following radiochemical separation. The ^{232}U tracer used was calibrated gravimetrically against a uranyl sulphate salt.

For samples collected during 2003, uranium was analysed directly on selected samples using isotope dilution mass spectrometry (PlasmaTrace 2 HR-ICP-MS). As yield determinant ^{233}U was used. Due to non-significant amounts of ^{234}U present in the ^{233}U tracer, two separate measurements were done for each sample, one with ^{233}U tracer in order to obtain concentrations of ^{238}U and one without tracer in order to obtain the $^{234}U/^{238}U$ ratio. The ^{233}U tracer was calibrated against a Merck multi-element standard as well as an Aldrich uranium standard solution. The detection limit for the procedure used for ^{238}U is lower than 1 nBq/l. The uncertainty given only considers the counting statistics. The detection limit was set as three times the standard deviation (based on counting statistics) of the blank value measured in 1% distilled nitric acid containing the same amount of yield determinant (^{233}U) as the samples.

6.3 Radium

For drinking water samples collected during 2001, radium was determined on 5-l water samples by direct radon emanation into Lucas scintillation cells after allowing storage of the water in gas-tight bottles for three weeks to reach radioactive equilibrium between ^{222}Rn and ^{226}Ra. For samples collected during 2002 and 2003, radium was determined by liquid scintillation counting. Radium was co-precipitated onto MnO_2 from 2-10 l water using ^{133}Ba as tracer. The MnO_2 was dissolved and Ra(Ba) co-precipitated onto $PbSO_4$ which in turn was dissolved in 6-8 ml alkaline EDTA solution, transferred to a liquid scintillation cell and a mineral-based scintillator (Opti Fluor O, Packard BioScience) added in order to collect the radon. After a radon ingrowth period of three weeks, the samples were counted on a Wallac Quantulus 1220 liquid scintillation spectrometer. The detection limit for the procedure used for analysis of radium is lower than 1 mBq/l based on analysis of blank samples containing only the chemicals used for the procedure. Uncertainty is based on counting statistics only.

6.4 Radon

Radon concentrations were determined using a liquid scintillation counter and methods described previously (Sundhedsstyrelsen, 1986). The detection limit is approximately 1 Bq/l and analytical uncertainties are estimated to be less than 10%. Radon concentrations were corrected for decay for the time from sampling to measurement using the ^{222}Rn half-life of 3.8 days.

7 Results

The locations of water works and water supplies from which samples of drinking water were collected are shown in Fig. 1. Sampling in 2001 covered Bornholm and those water works in the country with the highest production of drinking water. In 2002 sampling focused on Jutland including locations suggested by GEUS as potential sites for elevated levels of natural radionuclides in groundwater due to geological conditions. In 2003 sampling focused on Zealand, Funen and the southern part of Jutland including those water works and single supplies where the concentrations exceeded the screening levels. The locations in Fig. 1 are marked in dark colour if the concentrations of radioactivity were at the screening levels or higher. Most of the results were at or below the screening levels.

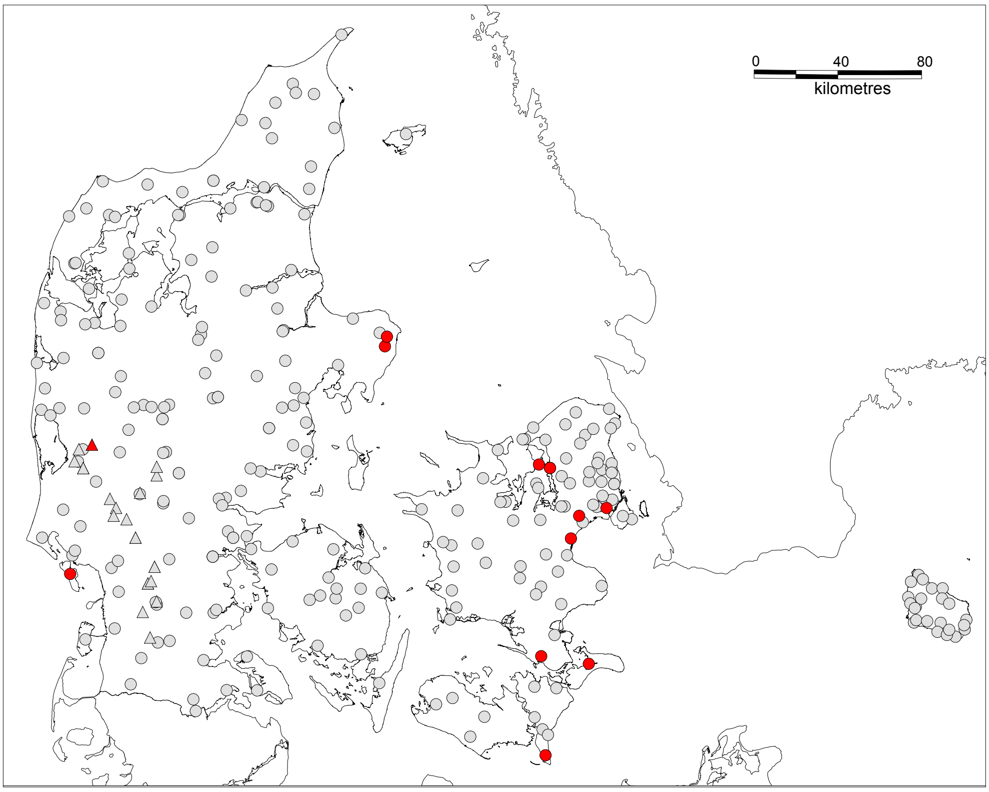

Fig. 1. Locations for sampling of drinking water marked with circles. The groundwater locations selected on geological grounds are marked with triangles. Dark coloured marks indicate that the screening levels were exceeded.

The analytical results are presented graphically in a scatterplot, Fig. 2, which shows total alpha versus total beta radioactivity concentrations in the samples analysed. The dashed lines indicate the screening levels.

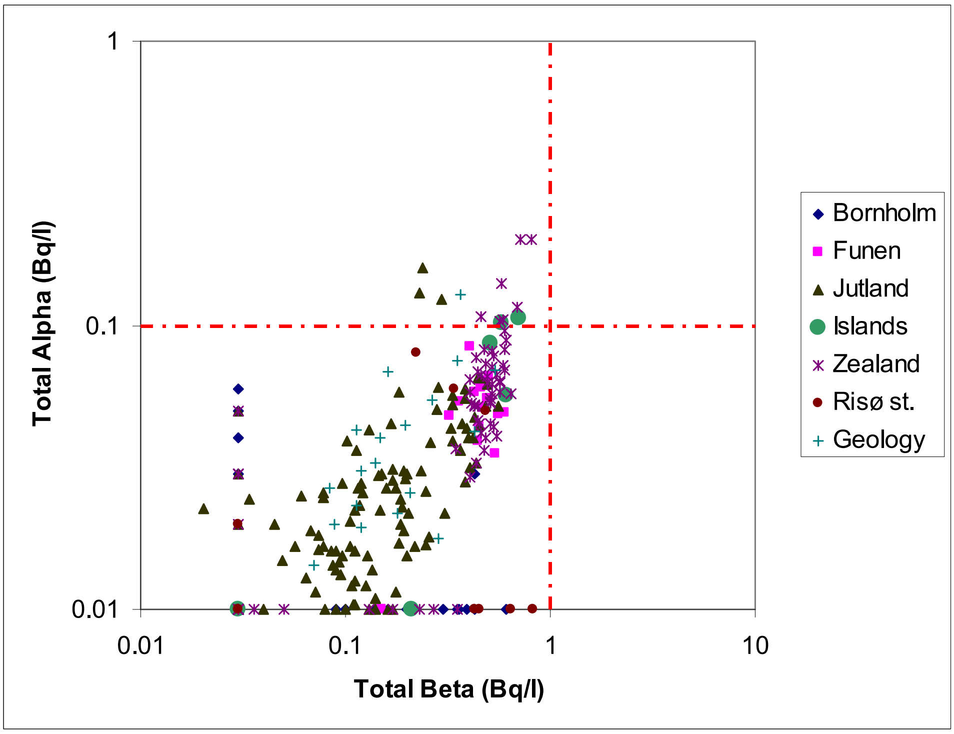

Fig. 2. Scatterplot of observed total alpha and beta radioactivity levels in drinking water in different part of the country. Untreated groundwater from borings selected for geological reasons are included marked with + . The screening levels are indicated by dashed lines.

Radon concentrations above the detection limit were found on Bornholm only, in agreement with a previous investigation of radon from Danish water works (National Board of Health, 1986). Radon concentrations in drinking water on Bornholm are higher in un-oxidized water at most sites compared to oxidized water.

The highest radon concentrations of 87 Bq/l are found at Vang. However, oxidized waters at the same water works only show radon concentrations of 43 and 48 Bq/l. The relatively high radon concentration in drinking water at Vang is not reflected in correspondingly high alpha and beta values.

Recommendations from the Nordic countries and from the European Commission suggest an exemption level for radon in drinking water of 100 Bq/l (Nordic Radiation Protection Authorities, 2000; Kommissionens henstilling, 2001). The radon values measured in samples of both oxidized and non-oxidized drinking water in this study are well below this level.

The detailed numerical results are given in the Appendix. The results of total alpha and beta radioactivity are given in Tables 1-5 for Zealand, the islands south of Zealand (Lolland, Falster and Møn), Jutland, Funen and Langeland, and Bornholm. Table 6 lists water works and supplies with levels of total alpha and beta radioactivity at the screening levels or higher. Tables 7 and 8 give results of total alpha and beta radioactivity including uranium and radium isotopes for locations with concentrations at the screening levels or higher. Table 9 gives results for the Risø monitoring stations of total alpha and beta radioactivity including uranium and radium isotopes. Table 10 gives the results of radioactivity in drinking water from untreated groundwater supplies in Jutland selected for geological reasons

The concentrations of total alpha and beta radioactivity in drinking water were generally found to be below the screening levels. Out of a total of 294 water supplies investigated, samples from 9 supplies (corresponding to 3%) have shown concentrations at the screening levels or higher. In all cases this was due to increased alpha radioactivity.

Concentrations of total alpha and beta radioactivity in drinking water above the screening levels were found near the following locations: Skjern, Ebeltoft, Grenå, Solrød, Stege, Vordingborg, Ishøj, Gedser, Jægerspris, Frederikssund, Hvidovre and Fanø. The highest levels of total alpha radioactivity in drinking water were found at Grenå and Ebeltoft in Jutland with levels up to 0.13 Bq/l and in Frederikssund on Zealand with levels up to 0.2 Bq/l. The water works in these areas were subject to a closer investigation with repeated sampling from individual bore holes and determination of total alpha and beta radioactivity including uranium and radium in these samples. The results demonstrate that the increased alpha radioactivity is due mainly to uranium in the drinking water. The variation of uranium concentrations is large between different boreholes from the same area. At Grenå the concentrations of ^{234}U and ^{238}U were found in the range 0.021-0.14 Bq/l (2-10 µg/l), in Ebeltoft in the range 0.008-0.027 Bq/l (0.8-2 µg/l), and in Frederikssund the uranium concentrations were found in the range 0.00002-0.22 Bq/l (2 ng/l – 15 µg/l).

Borings in the Frederikssund area showed generally the highest concentrations of ^{226}Ra, ranging from 0.005 to 0.018 Bq/l. Other water works with somewhat elevated ^{226}Ra concentrations were in Stege, Vordingborg, Gedser and Skjern with 0.011, 0.015, 0.014 and 0.035 Bq/l respectively. The remaining water works analysed showed ^{226}Ra concentrations generally below 0.005 Bq/l.

The elevated total alpha levels are generally explained by elevated uranium concentrations. Some exceptions were however found at Stege and Vordingborg with exceptionally low uranium concentrations. The elevated total alpha levels may in this case instead, at least partly, be explained by the elevated ^{226}Ra.

In some cases elevated total alpha concentrations may neither be explained by elevated uranium nor by ^{226}Ra concentrations. In these cases the contribution from other alpha emitters such as ^{210}Po and/or ^{228}Th with daughter products could play an important role (Parsa, 1998; Parsa et al., 1999).

8 Total Indicative Dose

The Total Indicative Dose from consumption of drinking water containing radioactivity may be estimated from the analytical data. An adult consuming two litres of drinking water per day containing 0.2 Bq/l of each of the two uranium isotopes ^{234}U and ^{238}U (about 20 µg/l) and 0.04 Bq/l of ^{226}Ra will receive an annual radiation dose of about 0.02 mSv. So even at the water works with the highest measured levels of alpha radioactivity, the annual doses are well below the parametric indicator value of 0.1 mSv/y specified in the EC Drinking Water Directive.

9 Conclusions

The results of this investigation demonstrate that Denmark fulfils the obligation to meet the requirements in the Drinking Water Directive 98/83/EC for radioactivity in drinking water used in Denmark. The investigation has included samples from Danish water works that produce more than 40% of the drinking water delivered to consumers.

The results show low concentrations of natural radioactivity in Danish drinking water and even the highest measured concentrations meet the required limit for the total indicative dose.

Groundwater used for drinking water was collected from very different types of geological structures including bed rock and areas with potentially elevated levels of natural radioactivity. Also in these cases the concentrations of radioactivity were sufficiently low to meet the requirements in the Drinking Water Directive.

In view of these results it seems probable that the risk of finding drinking water in Denmark with unacceptable concentrations of radioactivity is very small. Therefore there is no need for further radiological investigations of the Danish water supply based on natural groundwaters.

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11 APPENDIX – Analytical Results

The analytical results are given in Tables 1-10. Concentrations of total alpha and beta radioactivity and of uranium and radium isotopes in drinking water are given in becquerels per litre (Bq/l). Analytical results below detection limits are indicated (<DL).

Table	Region	Results
1	Zealand	Total alpha and beta radioactivity
2	Lolland, Falster and Møn	Total alpha and beta radioactivity
3	Jutland	Total alpha and beta radioactivity
4	Funen and Langeland	Total alpha and beta radioactivity
5	Bornholm	Total alpha and beta radioactivity
6	Supplies with concentrations above screening levels	Total alpha and beta radioactivity
7	Zealand	Total alpha and beta radioactivity including uranium and radium isotopes
8	Jutland, Lolland, Falster and Møn	Total alpha and beta radioactivity including uranium and radium isotopes
9	Risø monitoring stations	Total alpha and beta radioactivity including uranium and radium isotopes
10	Supplies selected for geological reasons	Total alpha and beta radioactivity including uranium and radium isotopes

Table 1. Total alpha and beta radioactivity (Bq/l) in drinking water from water works on Zealand.

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Bagsværd	Bagsværd	9525	10-Jun-2003	0.05	0.41
Birkerød	Birkerød	1007	8-Nov-2001	<0.01	0.23
Hornsherredværket	Bramnæs	1008	30-Aug-2001	<0.01	<0.03
Brøndbyøster	Brøndby	1062	24-Oct-2001	<0.01	<0.03
Brøndbyvester	Brøndby	1063	24-Oct-2001	<0.01	<0.03
Dianalund	Dianalund	9514	2-Jun-2003	0.04	0.48
Dragør	Dragør	9524	10-Jun-2003	0.10	0.60
Grevinge	Dragsholm	9527	11-Jun-2003	0.05	0.42
Farum	Farum	9533	16-Jun-2003	0.07	0.45
Endrup	Fredensborg-Humlebæk	9536	16-Jun-2003	0.04	0.34
Frederiksberg	Frederiksberg	9523	10-Jun-2003	0.09	0.61
Ådalsværket	Frederikssund	9563	7-Aug-2003	0.20	0.81
Marbæk	Frederiksund	9562	7-Aug-2003	0.20	0.71
Kappelhøj	Frederiksværk	9557	1-Jul-2003	0.08	0.52
Liseleje	Frederiksværk	9556	1-Jul-2003	0.04	0.48
Ermelundsværket	Gentofte	1001	2-Nov-2001	<0.01	0.04
Bregnegård	Gentofte	1066	2-Nov-2001	<0.01	<0.03
Glostrup	Glostrup	9521	10-Jun-2003	0.07	0.49
St. Fuglede	Gørlev	9564	8-Aug-2003	0.06	0.56
Slangerup	Gørløse	9529	16-Jun-2003	0.04	0.46
Udsholt	Græsted-Gilleleje	9561	7-Aug-2003	0.05	0.51
Greve	Greve	9503	28-May-2003	0.08	0.44
Haslev	Haslev	1014	1-Oct-2001	0.03	<0.03
Pindsobro	Haslev	9510	28-May-2003	0.06	0.52
Baunehøj, Helsinge	Helsinge	9560	7-Aug-2003	0.04	0.55
Espegærde	Helsingør	1068	8-Nov-2001	<0.01	<0.03
Hellebæk	Helsingør	1005	8-Nov-2001	<0.01	0.17
Snekkersten	Helsingør	1067	8-Nov-2001	<0.01	<0.03
Frederiksgade	Hillerød	1006	8-Nov-2001	<0.01	0.27
Stenholt	Hillerød	9535	16-Jun-2003	0.06	0.56
Regional, Vesterborg	Højreby	9519	3-Jun-2003	0.06	0.49
Langerød værk	Holbæk	9517	2-Jun-2003	0.06	0.51
Søndre værk	Holbæk	9516	2-Jun-2003	0.05	0.45
Høng	Høng	9515	2-Jun-2003	0.03	0.44
Sjælsø	Hørsholm	1004	2-Nov-2001	<0.01	0.13
Torplille	Hundested	1070	8-Nov-2001	<0.01	<0.03
Ullerup	Hundested	1069	8-Nov-2001	<0.01	<0.03
Hvidovre	Hvidovre	9568	11-Aug-2003	0.12	0.69
Thorsbro	Ishøj	9530	16-Jun-2003	0.11	0.46
Jægerspris	Jægerspris	9559	7-Aug-2003	0.14	0.57
Dejvad	Kalundborg	1101	1-Oct-2001	0.08	0.22
Faxe	Køge	9506	28-May-2003	0.07	0.50
Fruedal	Køge	9505	28-May-2003	0.07	0.52
Køge	Køge	1009	1-Oct-2010	<0.01	<0.03
Erdrup	Korsør	1013	1-Oct-2001	<0.01	0.05

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Lejre	Lejre	9501	26-May-2003	0.07	0.54
Dybendal	Lyngby-Tårbæk	9526	10-Jun-2003	0.05	0.44
Maribo	Maribo	9518	3-Jun-2003	0.05	0.43
Hjelmsølille	Næstved	1015	1-Oct-2001	<0.01	<0.03
Nørre Alslev	Nørre Alslev	9520	3-Jun-2003	0.08	0.53
Nykøbing Falster	Nykøbing Falster	1016	1-Oct-2001	0.03	<0.03
Nykøbing Rørvig	Nykøbing-Rørvig	9528	11-Jun-2003	0.06	0.64
Præstø	Præstø	9507	28-May-2003	0.08	0.48
Tystevad	Ringsted	9511	28-May-2003	0.05	0.51
Islevbro	Rødovre	9531	16-Jun-2003	0.06	0.40
Rødovre	Rødovre	9522	10-Jun-2003	0.07	0.59
Marbjerg	Roskilde	9500	26-May-2003	0.07	0.46
Marbjerg	Roskilde	1010	27-Sep-2001	<0.01	<0.03
Nordre værk	Skælskør	9565	8-Aug-2003	0.07	0.59
Stigsnæs	Skælskør	9566	8-Aug-2003	0.08	0.60
Skibby	Skibby	9558	6-Aug-2003	0.06	0.52
Regnemark	Skovbo	9512	28-May-2003	0.06	0.57
Valbygård	Slagelse	1012	1-Oct-2001	0.01	<0.03
Holte	Søllerød	1002	22-Oct-2001	0.05	<0.03
Nærum	Søllerød	1064	22-Oct-2001	<0.01	<0.03
Trørød	Søllerød	1065	22-Oct-2001	0.02	<0.03
Solrød	Solrød	9504	28-May-2003	0.10	0.59
Sorø	Sorø	9513	2-Jun-2003	0.03	0.41
Stenløse	Stenløse	9534	16-Jun-2003	0.06	0.41
St. Heddinge	Stevns	9567	8-Aug-2003	0.04	0.53
Tårnby	Tårnby	1003	22-Oct-2001	<0.01	0.35
Kvamløse-Tølløse	Tølløse	9502	26-May-2003	0.05	0.44
Søndersø	Værløse	9532	16-Jun-2003	0.05	0.51
Vordingborg	Vordingborg	9509	28-May-2003	0.10	0.56
Ølstykke	Ølstykke	1071	8-Nov-2001	<0.01	<0.03

Table 2. Total alpha and beta radioactivity (Bq/l) in drinking water from water works on Lolland, Falster and Møn.

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Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Stege	Møn	9508	28-May-2003	0.10	0.58
Nakskov	Nakskov	1017	1-Oct-2001	<0.01	0.21
Rødby	Rødby	1018	1-Oct-2001	<0.01	<0.03
Stubbekøbing	Stubbekøbing	9553	30-Jun-2003	0.09	0.51
Gedser, Kobbersøvej	Sydfalster	9555	30-Jun-2003	0.11	0.70
Marielyst	Sydfalster	9554	30-Jun-2003	0.06	0.61

Table 3. Total alpha and beta radioactivity (Bq/l) in drinking water from water works on Jutland

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Drastrup 1	Aalborg	9117	19-Sep-2002	0.03	0.08
Drastrup 2	Aalborg	9118	19-Sep-2002	0.03	0.19
Engkilde	Aalborg	9119	19-Sep-2002	0.02	0.19
Vissegård	Aalborg	9120	19-Sep-2002	0.02	0.08
Aars	Aars	9128	3-Oct-2002	0.01	0.11
Kibæk	Aaskov	9175	28-Oct-2002	0.02	0.06
Sønder Felding	Aaskov	9176	28-Oct-2002	0.02	0.07
Aulum	Aulum-Haderup	9154	29-Oct-2002	0.01	0.13
Billund Gl.	Billund	9581	9-Sep-2003	0.04	0.37
Billund Ny	Billund	9580	9-Sep-2003	0.06	0.39
Rødkærsbro	Bjerringbro	9179	30-Oct-2002	0.03	0.15
Outrup	Blåbjerg	9583	9-Sep-2003	0.07	0.44
Oksby & Ho	Blåvandshuk	9584	9-Sep-2003	<0.03	0.20
Bramming	Bramming	9549	26-Jun-2003	0.05	0.48
Ejke	Bramming	9550	26-Jun-2003	0.05	0.43
Brande	Brande	9155	28-Oct-2002	0.01	0.18
Pedersborg	Brande	9156	28-Oct-2002	0.02	0.20
Nordre vandværk	Brønderslev	9102	19-Sep-2002	0.03	0.38
Brovst, boring 3	Brovst	9112	19-Sep-2002	0.03	0.16
Brovst, boring 6	Brovst	9111	19-Sep-2002	0.02	0.13
Dronninglund	Dronninglund	9115	19-Sep-2002	0.02	0.03
Egedal	Ebeltoft	9190	21-Nov-2002	0.10	(3.92)[1]
Nord Vest værket	Egvad	9157	28-Oct-2002	0.05	0.28
Esbjerg, Klelund Plantage, 118 m	Esbjerg	9143	4-Oct-2002	0.02	0.09
Esbjerg, Klelund Plantage, 64 m	Esbjerg	9142	4-Oct-2002	0.03	0.08
Spangsbjerg	Esbjerg	1028	3-Sep-2001	<0.01	0.13
Vester Gjesing	Esbjerg	1029	3-Sep-2001	<0.01	<0.03
Fanø, Ringbyvej	Fanø	9585	9-Sep-2003	0.16	0.24
Frasø	Farsø	9129	3-Oct-2002	0.01	0.11
Almhus	Ferritslev	9123	19-Sep-2002	0.02	0.22
Follerup	Fredericia	1035	14-Nov-2001	<0.01	<0.03
Kongens Port	Fredericia	1053	14-Nov-2001	<0.01	<0.03
Tørskind	Fredericia	1036	14-Nov-2001	<0.01	<0.03
Tolne	Frederikshavn	9101	20-Sep-2002	0.01	0.35
Give, gammel	Give	1055	14-Nov-2001	<0.01	<0.03
Give, ny	Give	1054	14-Nov-2001	<0.01	<0.03
Gram, Åvej	Gram	9548	26-Jun-2003	0.07	0.46
Gram, Skjoldagervej	Gram	9547	26-Jun-2003	0.05	0.56
Gråsten	Gråsten	9544	19-Jun-2003	0.05	0.33
Havdal	Grenå	9195	21-Nov-2002	0.06	0.18
Homåvandværket	Grenå	9193	21-Nov-2002	0.13	0.23
Dolmer 1	Grenå	9194	21-Nov-2002	0.12	0.30

[1] Value not confirmed by repeated analysis

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Grindsted 2	Grindsted	1030	3-Sep-2001	<0.01	<0.03
Stenderup Kroager	Grindsted	9138	4-Oct-2002	0.01	0.09
Ansager	Grinsted	9140	4-Oct-2002	0.03	0.17
Fauerdal	Haderslev	9543	18-Jun-2003	0.06	0.39
Haderslev	Haderslev	1027	4-Sep-2001	<0.01	<0.03
Hadsten	Hadsten	9200	25-Nov-2002	0.05	0.17
Hadsund	Hadsund	9108	19-Sep-2002	0.06	0.33
Ulsted	Hals	9114	19-Sep-2002	0.03	0.25
Hammel	Hammel	9196	25-Nov-2002	0.01	0.06
Hanstholm, Frøstrup	Hanstholm	9184	22-Nov-2002	0.01	0.11
Hanstholm, Hanstholm	Hanstholm	9183	22-Nov-2002	0.01	0.05
Hedensted	Hedensted	1056	14-Nov-2001	<0.01	<0.03
Nordre vandværk	Herning	1043	15-Nov-2001	<0.01	0.08
Østre vandværk	Herning	1044	15-Nov-2001	<0.01	0.17
Snejbjerg	Herning	9158	29-Oct-2002	0.02	0.11
Hirtshals øst	Hirsthals	9103	20-Sep-2002	0.02	0.26
Hjørring	Hjørring	9124	19-Sep-2002	0.02	0.12
Hobro	Hobro	9109	18-Sep-2002	0.01	0.13
Frøjk	Holstebro	1046	15-Nov-2001	<0.01	<0.03
Holstebro	Holstebro	1045	15-Nov-2001	<0.01	<0.03
Højballegård	Horsens	1033	14-Nov-2001	<0.01	<0.03
Rugballegård	Horsens	1057	14-Nov-2001	<0.01	<0.03
Bøgil	Ikast	9161	29-Oct-2002	0.04	0.11
Ikast	Ikast	9160	29-Oct-2002	0.02	0.11
Almtoft Kjellerup	Kjellerup	9181	29-Oct-2002	0.03	0.10
Østre Værk	Kolding	1059	3-Sep-2001	<0.01	<0.03
Søndre vandværk	Kolding	1058	3-Sep-2001	<0.01	<0.03
Trudsbro	Kolding	1037	3-Sep-2001	0.03	<0.03
Læsø Central	Læsø	9125	19-Sep-2002	0.01	0.07
Lemvig	Lemvig	9162	30-Oct-2002	0.02	0.19
Ny Klosterhede	Lemvig	9163	30-Oct-2002	0.02	0.11
Røde Kors, Løgstør	Løgstør	9122	19-Sep-2002	0.04	0.33
Tinghøj	Løgstør	9121	19-Sep-2002	0.02	0.19
Løgumkloster	Løgumkloster	9576	10-Sep-2003	0.04	0.40
Løkken	Løkken-Vrå	9116	19-Sep-2002	0.02	0.19
Vrå	Løkken-Vrå	9104	20-Sep-2002	0.03	0.44
Mariager	Mariager	9199	21-Nov-2002	0.02	0.11
Nykøbing Mors	Morsø	9182	22-Nov-2002	0.03	0.12
Nibe	Nibe	9110	19-Sep-2002	0.03	0.14
Nordborg Hovedværk	Nordborg	9579	10-Sep-2003	0.04	0.45
Fjellerup	Nørre-Djurs	9202	21-Nov-2002	0.01	0.14
Agerskov	Nørre-Rangstrup	9575	10-Sep-2003	0.03	0.40
Branderup	Nørre-Rangstrup	9578	10-Sep-2003	0.04	0.42
Lindholm	Nørresundby	9113	19-Sep-2002	0.02	0.31
Odder, Hallingvej	Odder	9198	25-Nov-2002	0.02	0.08
Odder, Ulfsborgvej	Odder	9197	25-Nov-2002	0.04	0.13
Padborg, Toldbodvej	Padborg	9545	19-Jun-2003	0.03	0.23

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Padborg, Vejbækvej	Padborg	9546	19-Jun-2003	0.04	0.33
Oust Mølle	Randers	1042	3-Sep-2001	0.05	<0.03
Strømmen	Randers	1076	14-Nov-2001	<0.01	<0.03
Skindermarken	Ribe	1032	3-Sep-2001	<0.01	<0.03
Holmsland	Ringkøbing	9159	29-Oct-2002	0.02	0.15
Lybæk vandværk	Ringkøbing	9165	28-Oct-2002	0.02	0.09
Preben Jørgensen	Ringkøbing	9152	29-Oct-2002	0.04	0.26
Ringkøbing	Ringkøbing	9164	28-Oct-2002	0.01	0.11
Rønde	Rønde	9201	25-Nov-2002	0.02	0.20
Ørnedal	Sæby	9105	20-Sep-2002	0.01	0.11
Glyngøre vandværk	Sallingsund	9185	22-Nov-2002	0.02	0.09
Mou	Sejlflod	9126	3-Oct-2002	0.03	0.06
Gudenå	Silkeborg	1073	15-Nov-2001	<0.01	<0.03
Hvinningdal	Silkeborg	1041	14-Nov-2001	<0.01	0.16
Søholt	Silkeborg	1072	15-Nov-2001	<0.01	0.04
Sindal	Sindal	9107	20-Sep-2002	0.01	0.07
Skærbæk	Skærbæk	9577	10-Sep-2003	0.05	0.37
Skagen 2	Skagen	9106	20-Sep-2002	0.00	0.20
Dyrhave	Skanderborg	1074	14-Nov-2001	<0.01	<0.03
Fredensborg	Skanderborg	1075	14-Nov-2001	<0.01	<0.03
Skive	Skive	1048	17-Nov-2001	<0.01	<0.03
Grønnegade	Skjern	1047	15-Nov-2001	<0.01	<0.03
Miang Dam	Sønderborg	1025	4-Sep-2001	<0.01	<0.03
Regional vandværk	Spøttrup	9180	30-Oct-2002	0.02	0.07
Støvring	Støvring	9127	3-Oct-2002	0.02	0.05
Kobbelhøj	Struer	9167	30-Oct-2002	0.01	0.09
Struer	Struer	9166	30-Oct-2002	0.01	0.08
Hurup vandværk, Kløvermarken	Sydthy	9188	22-Nov-2002	0.03	0.20
Hurup vandværk, Sundsvej 2	Sydthy	9187	22-Nov-2002	0.01	0.09
Baun	Thisted	1049	16-Nov-2001	<0.01	0.10
Nørre Vorupør	Thisted	9189	23-Nov-2002	0.02	0.07
Vang	Thisted	1050	16-Nov-2001	<0.01	0.14
Engbjerg	Thyborøn-Harboøre	9168	30-Oct-2002	0.03	0.17
Thyholm	Thyholm	9169	28-Oct-2002	0.06	0.28
Tønder	Tønder	1023	3-Sep-2001	0.02	<0.03
Vildbjerg	Trehøje	9170	29-Oct-2002	0.02	0.25
Fjand	Ulfborg-Vemb	9172	29-Oct-2002	0.02	0.18
Vemb	Ulfborg-Vemb	9171	29-Oct-2002	0.01	0.09
Varde	Varde	1031	3-Sep-2001	<0.01	<0.03
Vejen	Vejen	9551	26-Jun-2003	0.06	0.49
Grejsdal	Vejle	1060	14-Nov-2001	<0.01	<0.03
Lysholt	Vejle	1034	14-Nov-2001	<0.01	<0.03
Søndre Værk	Vejle	1061	14-Nov-2001	<0.01	<0.03
City	Viborg	1051	17-Nov-2001	<0.01	<0.03
Viborg Nord	Viborg	9177	30-Oct-2002	0.04	0.10
Viborg Syd	Viborg	9178	30-Oct-2002	0.03	0.11
Spjald	Videbæk	9173	28-Oct-2002	0.02	0.10

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Vinderup	Vinderup	9174	30-Oct-2002	0.02	0.02
Vojens	Vojens	1026	4-Sep-2001	<0.01	<0.03
Ølgod	Ølgod	9582	9-Sep-2003	0.04	0.39
Åbenrå	Åbenrå	1024	4-Sep-2001	<0.01	<0.03
Ålestrup	Ålestrup	9186	21-Nov-2002	0.01	0.08
Århus, Åboværk	Århus	9191	25-Nov-2002	0.03	0.17
Århus, Bederværket	Århus	9192	25-Nov-2002	0.03	0.12
Kasted	Århus	1038	17-Nov-2001	<0.01	<0.03
Stautrup	Århus	1039	17-Nov-2001	<0.01	<0.03
Truelsbjerg	Århus	1040	17-Nov-2001	<0.01	0.09

Table 4. Total alpha and beta radioactivity (Bq/l) in drinking water from water works on Funen and Langeland.

Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Kildebakken	Assens	9574	8-Sep-2003	0.06	0.46
Tyrekrog	Bogense	9552	26-Jun-2003	0.06	0.49
Ejby	Ejby	9541	18-Jun-2003	0.06	0.43
Kaleko	Fåborg	9573	8-Sep-2003	0.04	0.45
Kerteminde	Kerteminde	9569	8-Sep-2003	0.05	0.56
Rønninge	Langeskov	9538	18-Jun-2003	0.04	0.44
Stauerbyskov	Middelfart	9542	18-Jun-2003	0.08	0.40
Hjulby bro	Nyborg	9537	18-Jun-2003	0.05	0.60
Borreby	Odense	1022	3-Sep-2001	<0.01	<0.03
Holmehave	Odense	1019	3-Sep-2001	<0.01	0.15
Hovedværket	Odense	1020	3-Sep-2001	<0.01	<0.03
Lindved	Odense	1021	3-Sep-2001	<0.01	<0.03
Otterup	Otterup	9570	8-Sep-2003	0.05	0.32
Ringe	Ringe	9540	18-Jun-2003	0.07	0.50
Lejrbølle	Rudkøbing	9572	8-Sep-2003	0.04	0.54
Svendborg	Svendborg	9571	8-Sep-2003	0.05	0.47
Nr. Lyndelse	Årslev	9539	18-Jun-2003	0.05	0.36

Table 5. Total alpha and beta radioactivity (Bq/l) in drinking water from water works on Bornholm.

Water Work	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Allinge	1077	29-Oct-2001	<0.01	0.03
Balka strand	1090	30-Oct-2001	<0.01	0.09
Boderne	1097	30-Oct-2001	<0.01	0.39
Gøngeherred	1094	30-Oct-2001	<0.01	<0.03
Gudhjem	1079	29-Oct-2001	<0.01	0.20
Hasle	1083	29-Oct-2001	<0.01	0.43
Klemensker	1086	29-Oct-2001	0.04	<0.03
Lobbæk	1096	30-Oct-2001	<0.01	<0.03
Muleby	1085	29-Oct-2001	<0.01	0.61
Nexø	1088	30-Oct-2001	0.06	<0.03
Nyker	1084	29-Oct-2001	<0.01	0.14
Pedersker	1099	30-Oct-2001	0.01	0.45
Rø	1078	29-Oct-2001	0.03	<0.03
Robbedale	1093	30-Oct-2001	<0.01	<0.03
Smålyng	1095	30-Oct-2001	<0.01	<0.03
Snogebæk	1089	30-Oct-2001	<0.01	0.36
Sømarken	1098	30-Oct-2001	0.05	<0.03
Stampen	1092	30-Oct-2001	<0.01	0.10
Strandmarken	1091	30-Oct-2001	<0.01	0.16
Tejn	1080	29-Oct-2001	<0.01	0.35
Vang	1087	29-Oct-2001	<0.01	0.20
Østerlars	1081	29-Oct-2001	0.01	0.30
Østermarie	1082	29-Oct-2001	0.03	0.43

Table 6. Total alpha and beta radioactivity (Bq/l) in drinking water from water works with concentrations at screening levels or higher.

Region	Water Work	Municipality	Sample ID	Sample Date	Alpha (Bq/l)	Beta (Bq/l)
Jutland	Egedal	Ebletoft	9190	21-Nov-2002	0.10	(3.92)[2]
Jutland	Fanø, Ringbyvej	Fanø	9585	9-Sep-2003	0.16	0.24
Jutland	Homå	Grenå	9193	21-Nov-2002	0.13	0.23
Jutland	Dolmer 1	Grenå	9194	21-Nov-2002	0.12	0.30
Jutland	Simon Villumsen	Skjern	9130	3-Oct-2002	0.13	0.37
Lolland, Falster and Møn	Stege	Møn	9508	28-May-2003	0.10	0.58
Lolland, Falster and Møn	Gedser, Kobbersøvej	Sydfalster	9555	30-Jun-2003	0.11	0.70
Zealand	Ådal	Frederikssund	9563	7-Aug-2003	0.20	0.81
Zealand	Marbæk	Frederiksund	9562	7-Aug-2003	0.20	0.71
Zealand	Hvidovre	Hvidovre	9568	11-Aug-2003	0.12	0.69
Zealand	Thorsbro	Ishøj	9530	16-Jun-2003	0.11	0.46
Zealand	Jægerspris	Jægerspris	9559	7-Aug-2003	0.14	0.57
Zealand	Solrød	Solrød	9504	28-May-2003	0.10	0.59
Zealand	Vordingborg	Vordingborg	9509	28-May-2003	0.10	0.56

[2] Value not confirmed by repeated analysis

Table 7. Total alpha and beta radioactivity including uranium and radium isotopes in drinking water from locations on Zealand, Lolland, Falster and Møn with concentrations at screening levels or higher.

Water Work	Municipality	Sample ID	Sample Date	Beta (Bq/l)	Alpha (Bq/l)	U-238 (Bq/l)	U-234 (Bq/l)	Ra-226 (Bq/l)
Ådalen	Frederikssund	9563	7-Aug-2003	0.81	0.20	0.092	0.099	0.0098
Ådalen, boring 192-1055	Frederikssund	9601	26-Nov-2003	0.60	0.09	0.019	0.021	0.013
Ådalen, boring 192-827	Frederikssund	9604	26-Nov-2003	0.40	0.06	0.0005	0.0008	0.015
Ådalen, boring 192-828	Frederikssund	9602	26-Nov-2003	0.55	0.11	0.066	0.063	0.009
Ådalen, boring 192-876	Frederikssund	9603	26-Nov-2003	0.43	0.06	0.0032	0.0039	0.016
Ådalen, boring 192-891	Frederikssund	9600	26-Nov-2003	0.90	0.07	0.147	0.179	0.014
Marbæk	Frederikssund	9562	7-Aug-2003	0.71	0.20	0.080	0.091	0.018
Marbæk, boring 192-613	Frederikssund	9605	26-Nov-2003	0.45	0.16	0.132	0.177	0.016
Marbæk, boring 192-614	Frederikssund	9606	26-Nov-2003	0.44	0.07	0.0036	0.0044	0.017
Marbæk, boring 192-714	Frederikssund	9607	26-Nov-2003	0.37	0.05	0.00002	0.00007	0.017
Marbæk, boring 199-945	Frederikssund	9609	26-Nov-2003	0.64	0.10	0.068	0.099	0.017
Marbæk, boring 199-946	Frederikssund	9608	26-Nov-2003	1.03	0.33	0.184	0.220	0.014
Marbæk, boring 199-947	Frederikssund	9610	26-Nov-2003	0.52	0.21	0.095	0.127	0.0054
Hvidovre	Hvidovre	9568	11-Aug-2003	0.69	0.12	0.025	0.028	0.0033
Thorsbro	Ishøj	9530	16-Jun-2003	0.46	0.11	0.033	0.039	0.0056
Jægerspris	Jægerspris	9559	7-Aug-2003	0.57	0.14	0.044	0.048	0.0075
Solrød	Solrød	9504	28-May-2003	0.59	0.10	0.018	0.022	0.0063
Mørkeskov	Vordingborg	9509	28-May-2003	0.56	0.10	0.00001	0.00003	0.015
Stege	Møn	9508	28-May-2003	0.58	0.10	0.000002	0.00002	0.011
Gedser	Sydfalster	9555	30-Jun-2003	0.70	0.11	0.0002	0.0005	0.014

Table 8. Total alpha and beta radioactivity including uranium and radium isotopes in drinking water from locations in Jutland with concentrations at screening levels or higher.

Water Work	Municipality	Sample ID	Sample Date	Beta (Bq/l)	Alpha (Bq/l)	U-238 (Bq/l)	U-234 (Bq/l)	Ra-226 (Bq/l)
Egedal	Ebeltoft	9190	21-Nov-2002	(3.92)[3]	0.10	0.010	0.010	0.0015
Egedal, boring 910018	Ebeltoft	9598	30-Oct-2003	<0.1	0.04	0.011	0.010	0.0013
Egedal, boring 910025	Ebeltoft	9595	30-Oct-2003	0.11	<0.03	0.0082	0.0088	0.0006
Egedal, boring 910029	Ebeltoft	9599	30-Oct-2003	0.12	<0.03	0.010	0.011	0.0020
Egedal, boring 910035	Ebeltoft	9596	30-Oct-2003	0.15	0.06	0.028	0.028	0.0032
Egedal, boring 910036	Ebeltoft	9597	30-Oct-2003	0.12	0.05	0.026	0.026	0.0027
Grenå	Grenå	9193	21-Nov-2002	0.23	0.13	0.067	0.072	0.0030
Dolmer 1	Grenå	9194	21-Nov-2002	0.30	0.12	0.083	0.097	0.0006
Dolmer, boring 710135	Grenå	9586	29-Oct-2003	0.28	0.19	0.080	0.095	0.0009
Dolmer, boring 710136	Grenå	9587	29-Oct-2003	0.32	0.22	0.091	0.107	0.0011
Dolmer, boring 710137	Grenå	9588	29-Oct-2003	0.26	0.15	0.057	0.068	0.0007
Dolmer, boring 710261	Grenå	9590	29-Oct-2003	0.30	0.22	0.092	0.108	0.0006
Dolmer, boring 710268	Grenå	9589	29-Oct-2003	0.30	0.18	0.075	0.088	0.0011
Homå, boring 710393	Grenå	9591	29-Oct-2003	<0.1	0.08	0.032	0.034	0.0024
Homå, boring 710394	Grenå	9593	29-Oct-2003	0.18	0.15	0.079	0.078	0.0015
Homå, boring 710443	Grenå	9592	29-Oct-2003	0.11	0.07	0.021	0.025	0.0013
Homå, boring 710448	Grenå	9594	29-Oct-2003	0.21	0.25	0.125	0.141	0.0017

[3] Value not confirmed from repeated analysis

Table 9. Total alpha and beta radioactivity including uranium and radium isotopes in water from Risø monitoring stations.

Risø monitoring stations	Municipality	Sample ID	Sample date	Alpha (Bq/l)	Beta (Bq/l)	U-238 (Bq/l)	U-234 (Bq/l)	Ra-226 (Bq/l)
Væggerløse	Sydfalster	1100	3-Dec-2001	0.02	<0.03	0.0001	0.0002	0.002
Dejgvad	Kalundborg	1011	31-Aug-2001	0.08	0.22	0.0012	0.0017	0.005
Feldbak	Hadsund	1102	16-Nov-2001	<0.01	0.83	0.0005	0.0005	0.024
Ravnholt	Ørbæk	1103	3-Sep-2001	0.06	0.34	0.011	0.012	0.003
Kongsted	Fredericia	1104	14-Nov-2001	0.05	0.48	0.0024	0.003	0.003
Fårtoft	Thisted	1105	16-Nov-2001	<0.01	0.45	0.0043	0.0054	0.001
Hvidsten	Purhus	1106	14-Nov-2001	<0.01	0.43	0.0003	0.0003	0.001
Rømø	Skærbæk	1107	15-Nov-2001	<0.01	0.64	0.0002	0.0002	0.004
Robberdale	Bornholm	1093	30-Oct-2001	<0.01	<0.03	0.0002	0.0003	0.007
Gøngeherred	Bornholm	1094	30-Oct-2001	<0.01	<0.03	0.0001	0.0002	0.002

Table 10. Radioactivity in drinking water from single supplies in Jutland selected from geological characteristics.

Name of supply	Municipality	Sample ID	Sample date	Alpha (Bq/l)	Beta (Bq/l)	U-238 (Bq/l)	U-234 (Bq/l)	Ra-226 (Bq/l)
S.H. Mathiasen, Brande	Brande	9136	5-Oct-2002	0.02	0.18			
Dines Holm Andersen, 180 m	Brørup	9145	4-Oct-2002	0.04	0.20			
Dines Holm Andersen, privat	Brørup	9144	4-Oct-2002	0.04	0.42			
ESØ Deponigas A/S, Tarm	Egvad	9133	3-Oct-2002	0.07	0.16			
ESØ Deponigas A/S, Tarm	Egvad	9134	3-Oct-2002	0.05	0.27			
Tomas Jensen, Lønborg	Egvad	9132	3-Oct-2002	0.01	0.09			
Esbjerg, Klelund Plantage, 118 m	Esbjerg	9143	4-Oct-2002	0.02	0.09			
Esbjerg, Klelund Plantage, 64 m	Esbjerg	9142	4-Oct-2002	0.03	0.08			
Arnum værk	Gram	9151	4-Oct-2002	0.02	0.11			
Gram & Nybøl Godser A/S	Gram	9148	4-Oct-2002	0.07	0.54			
Eigild Hansen, Grindsted	Grindsted	9135	5-Oct-2002	0.02	0.12			
Gunnar Kristensen	Helle	9139	5-Oct-2002	0.03	0.21			
Jørgen Uhd, Rurup	Nørre Rangstrup	9150	4-Oct-2002	0.03	0.14			
Kjeld Fogh, 135 m	Rødding	9146	4-Oct-2002	0.03	0.12			
Kjeld Fogh, 80 m	Rødding	9147	4-Oct-2002	0.04	0.11			
Niels Hansen	Rødding	9149	5-Oct-2002	0.04	0.15			
Niels Holger Nielsen	Skjern	9131	3-Oct-2002	0.01	0.07			
Simon Villumsen	Skjern	9130	3-Oct-2002	0.13	0.37	0.0015	0.002	0.036
Keld Uglebjerg	Varde	9141	5-Oct-2002	0.08	0.35			
Skovlund værk	Ølgod	9137	4-Oct-2002	0.02	0.29			

Table 11. Radon concentrations (Bq/l) in drinking water from water works on Bornholm. Results from a previous study are shown for comparison (Sundhedsstyrelsen, 1986).

Water work	Sampled before oxidation (Bq/l)	Sampled after oxidation (Bq/l)	1986 Study (Bq/l)
Robbedale	1.6		7.1
Robbedale	1.9		
Robbedale		< 1	
Robbedale		< 1	
Stampen	5.1		13.0
Stampen	3.0		4.4
Stampen		< 1	
Stampen		2.0	
Gøngeherred	2.8		6.1
Gøngeherred	1.8		7.8
Gøngeherred		< 1	
Gøngeherred		< 1	
Vang vandværk	87		150.0
Vang vandværk	87		18.0
Vang vandværk		43	
Vang vandværk		48	
Hasle vandværk	8.9		11.0
Hasle vandværk	6.5		11.0
Hasle vandværk		11	
Hasle vandværk		11	
Nyker	12		6.6
Nyker	11		
Nyker		3.9	
Nyker		3.1	
Muleby	9.4		10.0
Muleby	6.6		
Muleby	13		21.0
Muleby	12		
Muleby		3.9	
Muleby		2.6	
Allinge	19		40.0
Allinge	18		
Allinge		8.1	
Allinge		9.1	
Rø	< 1		
Rø	1.9		
Rø		< 1	4.0
Rø		< 1	9.9
Gudhjem	< 1		
Gudhjem	2.9		
Gudhjem		3.7	
Gudhjem		1.8	
Tejn	27.0		
Tejn	21.2		30.0
Tejn		22.5	16.0
Tejn		19.6	
Klemensker	18.4		5.5

Water work	Sampled before oxidation (Bq/l)	Sampled after oxidation (Bq/l)	1986 Study (Bq/l)
Klemensker	19.0		
Klemensker		63.9	
Klemensker		64.6	
Østerlars	11.5		
Østerlars	10.7		
Østerlars	27.7		< 1
Østerlars	26.6		10.0
Østerlars	3.6		
Østerlars	4.3		
Østerlars		< 1	
Østerlars		< 1	
Nexø	60.5		150.0
Nexø	63.9		53.0
Nexø		25.8	47.0
Nexø		26.5	23.0
Strandmarken	2.4		3.3
Strandmarken	2.2		
Strandmarken		< 1	
Strandmarken		< 1	
Sømarken	1.1		3.4
Sømarken	1.1		3.6
Sømarken		6.4	
Sømarken		7.8	
Snogebæk	< 1		5.3
Snogebæk	3.6		7.6
Snogebæk		< 1	
Snogebæk		1.0	
Balka strand	1.3		7.9
Balka strand	5.2		
Balka strand		< 1	
Balka strand		0.8	
Lobbæk	49		47.0
Lobbæk	44		12.0
Lobbæk		22	
Lobbæk		23	
Små Lysnæsværket	7.3		8.7
Små Lysnæsværket	8.9		8.4
Små Lysnæsværket		0.6	2.4
Små Lysnæsværket		< 1	< 1
Pedersker	< 1		7.2
Pedersker	1.0		
Pedersker		< 1	
Pedersker		< 1	
Boderne	40		58.0
Boderne	39		
Boderne		14	
Boderne		18	

Table 12. Radon concentrations (Bq/l) in drinking water from waterworks on Zealand.

Water work	Sampled before oxidation (Bq/l)	Sampled after oxidation (Bq/l)
Marbjerg		< 1
Marbjerg		< 1
Lejre		< 1
Lejre		< 1
Tølløse		< 1
Tølløse		< 1
Greve vandværk		< 1
Greve vandværk		< 1
Greve vandværk	< 1	
Greve vandværk	< 1	
Solrød vandværk		< 1
Solrød vandværk		< 1
Fruedal vandværk		< 1
Fruedal vandværk		< 1
Fakse vandværk		< 1
Fakse vandværk		< 1
Præstø vandværk		< 1
Præstø vandværk		< 1
Stege vandværk		< 1
Stege vandværk	< 1	
Stege vandværk	< 1	
Stege vandværk		< 1
Nørreskov v.v.		< 1
Nørreskov v.v.		< 1
Nørreskov v.v.	< 1	
Nørreskov v.v.	< 1	
Pindso Bro v.v.		< 1
Pindso Bro v.v.		< 1
Tystevad v.v.		< 1
Tystevad v.v.		< 1
Regnemarkværket		< 1
Regnemarkværket		< 1